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The Effect of Dynamometer Inertia Increment and Power Setting on Emissions and Fuel Economy for Motorcycles

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for Motorcycles**

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16. Abstract In developing the motorcycle regulations, the increment of inertia weight to be set on the dynamometer was picked as 10kg. To provide data to support the choice of an inertia increment, the effect of inertia on emissions and fuel economy needed to be quantitatively defined. Since road load horsepower setting is based on inertia increment, its effect on emissions and fuel economy required evaluation. A test program involving measuring emissions and fuel economy at various inertia and road load horsepower settings was conducted. Also evaluated was the magnitude of variations in the actual distance covered while driving the UDDS, and determine the effects on emissions and fuel economy.				
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ABSTRACT

The effects of dynamometer inertia increment and horsepower are determined from dynamometer tests of two motorcycles. An inertia increment of 10 kg is recommended based on the data. Data on the effects of actual driving distance on emissions and fuel economy, as measured by a dynamometer roll counter, are also presented.

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INTRODUCTION

In developing the motorcycle regulations, the increment of inertia weight to be set on the dynamometer was picked as 10 kg.* For example, any motorcycle with a loaded vehicle mass of 256 to 265 kg would be tested at a dynamometer inertia setting of 260 kg. Corresponding to the inertia setting, a road load horsepower also would be set on the dynamometer; the horsepower increment is approximately .04 horsepower per 10 kg inertia increment.

Several comments were received concerning the inertia increment. Concern was voiced within EPA that the inertia increment might need to be smaller, 5 kg for example, in order to minimize any bias to the fuel economy measurement. In a comment to the ANPRM, Honda presented an opposing point of view. They felt a 20 kg increment was sufficient, and stated their data showed little effect on emissions. No data were presented, however.

To evaluate these comments, and to provide data to support the choice of an inertia increment, the effect of inertia on emissions and fuel economy needed to be quantitatively defined. And since road load horsepower setting, as currently defined in the draft regulations, is based on inertia increment, its effect on emissions and fuel economy required evaluation. A test program involving measuring emissions and fuel economy at various inertia and road load horsepower settings was conducted. Two motorcycles, a Honda CB360 and a Yamaha 125 Enduro, were tested on a Shibaura dynamometer using the Urban Dynamometer Driving Schedule (UDDS). The Honda was chosen as representative of a middle weight 4-stroke motorcycle, the 2-stroke Yamaha representing the lighter weight motorcycles. The inertia weights of the motorcycles, with an 80 kg rider, are

Honda CB360	345 kg
Yamaha 125 Enduro	195 kg

An attempt was made to test the lightest motorcycle available at EPA, the Honda CT70 at 135 kg, but it could not come close to following the driving trace.

A secondary objective was to evaluate the magnitude of variations in the actual distance covered while driving the UDDS, and determine the effects on emissions and fuel economy. It was felt that actual driven distances may vary, and that if emissions and economy were calculated using the standard distance, an error would result. Therefore, a dynamometer roll revolution counter was installed and driving distance data were generated.

Summary and Conclusions

- For a 5 kg change in inertia and a .02 change in dynamometer horsepower (the maximum combined test deviation from the actual

*The smallest inertia increment available on the Shibaura dynamometer is also 10 kg.

inertia and road load horsepower for a 10 kg inertia increment), the effect on fuel economy is less than 1/2 percent of nominal value.

- The maximum effect on emissions for a 5 kg change in inertia and a .02 change in road load horsepower is less than 2 percent for NO_x . The effects on CO and HC are less than 1 percent.
- The results of this test series are expected to be applicable to other uncontrolled motorcycles and to controlled motorcycles with the exception of the percentage change in NO_x mass emissions, which could increase with certain control techniques.
- Based on these data, a 10 kg inertia increment is recommended.
- Variations of up to 3 percent of the standard test distance were encountered. It is expected that similar variations in emissions and fuel economy could occur if calculated using the standard test distance. Future evaluation is recommended.

Discussion

A. Effect of Inertia Increment

Bag 1 and 2 (hot start) tests were performed using the Honda CB160 and the Yamaha 125 Enduro. Inertia setting was varied with 3 repeat tests performed at each inertia setting, as shown in Table 1.

Table 1

Test Series-Dynamometer Inertia

Motorcycle	# of Inertia Settings	# of Tests at Each Setting	Range of Inertias Tested	Dynm Horsepower @ 50 mph
Honda CB160	11	3	200 - 300 kg	5.8
Yamaha 125 Enduro	9	3	150 - 250 kg	4.9

The test to test repeatability at a given inertia setting was good, as shown in the Appendix.

The measured dynamometer roll distance varied up to 3 percent of the standard distance. The data, calculated using the standard and measured distances, were compared; the data using measured distance showed the higher degree of correlation. Therefore measured distance was used in all the calculations for this test series.

To determine the relationship between emissions (economy) and dynamometer inertia, a linear regression analysis was performed. The means

of the three tests at each inertia setting were calculated, and the regression equation was determined using the means. The regression equation has the form,

$$\text{Emissions} = a_1 \times \text{inertia} + a_0$$

where a_1 is the slope, i.e., the rate of change of emissions per unit of inertia.

With inertia set on the dynamometer in increments of 10 kg, the largest possible deviation of actual inertia from the test value is 5 kg, i.e., one half the increment. Table II presents the effects on emissions and fuel economy of a 5 kg change in inertia. In interpreting the results, the level of correlation, as presented in the Appendix, should be taken into consideration.

Table II

Change Due to a 5 kg Change in Inertia

<u>Motorcycle</u>	<u>Parameter</u>	<u>% Change from Nominal Value</u>	<u>Magnitude of Change</u>
Honda CB360	CO	.30	.11 gms/km
	HC	.65	.01 gms/km
	NO _x	1.1	.003 gms/km
	Economy	-.25	-.06 km/l
Yamaha 125 Enduro	CO	(1)	(1)
	HC	.38	.05 gms/km
	NO _x	(2)	(2)
	Economy	-.33	-.08 km/l

- (1) Insufficient correlation at a 95% confidence level to allow prediction.
- (2) The NO_x emissions from current 2 strokes are so low (v1 ppm) that any effect could not be measured.

B. Effect of Dynamometer Horsepower

Bag 1 hot start tests using the Honda CB360 were run to determine the effect on emissions and fuel economy of dynamometer horsepower. Tests on a lighter, low power motorcycle were not completed because the motorcycle could not operate over a wide enough range of dynamometer horsepower settings. Table III describes the tests performed using the Honda.

Table III

Test Series-Dynamometer Horsepower

<u>Motorcycle</u>	<u># of HP Settings</u>	<u># of tests at each HP Setting</u>	<u>Range of dyno HP Settings Tested</u>	<u>Inertia kg</u>
Honda CB360	7	5	4.7 - 7.7	250

A linear regression analysis was also performed on these data to determine the relationship between emissions (fuel economy) and dynamometer horsepower. The regression statistics are shown in the Appendix.

The road load horsepower increment corresponding to the proposed 10 kg inertia increment is .04 horsepower. The maximum variation of the actual road load horsepower from the dynamometer setting is one half the increment, or .02 horsepower. Table IV presents the effects on emissions and economy for a .02 horsepower change. There was insufficient correlation of HC emissions to predict a relationship.

Table IV

Change Due to a .02 Change in Dynamometer HP Setting

<u>Motorcycle</u>	<u>Parameter</u>	<u>% Change from Nominal Value</u>	<u>Magnitude of Change</u>
Honda CB360	CO	.04	.015 gm/km
	NO _x	.44	.001 gm/km
	Economy	-.06	-.014 km/l

G. Combined Effect of Road Load Horsepower and Inertia

If a motorcycle is tested at a higher than actual inertia, the corresponding dynamometer horsepower setting may also be high. Therefore, the maximum effect on the motorcycle's emissions and fuel economy is the superposition of the independent effects. For the proposed 10 kg inertia increment, the combined effects on emissions and economy are small, less than 2 percent for all emission parameters and less than 1/2 percent for economy.

The magnitudes of the effects do not support the necessity of a 5 kg inertia increment. A larger increment, such as 20 kg, is also not recommended due to the uncertainty of the applicability of the NO_x results to controlled motorcycles. Therefore, based on these data, the 10 kg inertia increment, as proposed in the ANPRM, is the best choice.

D. Applicability to Other Motorcycles

It is anticipated that the percentage change in emissions and fuel economy due to inertia increment will be of the same magnitude for all uncontrolled motorcycles. Comparison of the Yamaha and Honda data show the same order of magnitude effects. The Yamaha is representative of the lightest class of motorcycles, and the effect of inertia increment should be the worst case for this motorcycle. In any case the ratio of inertia increment to total motorcycle inertia only varies between 1 1/2 to 3 1/2 percent for the heaviest (HD 1200) to lightest (Honda CT 70) motorcycle. Thus, the effect of inertia increment is a small percent of the total inertia for all motorcycles, and the effects determined in this test series should be of the same order of magnitude for all motorcycles.

For controlled motorcycles the percentage change in emissions and economy is difficult to predict due to the uncertainty of the control techniques. A likely control method which may increase the effects determined from these data is leaning the air fuel ratio. At leaner mixtures the rate of formation of NO_x increases and could result in percentage changes in NO_x mass emissions due to inertia increment several times larger than determined from these tests.

E. Physical Interpretation of the Effect of Horsepower and Inertia

The increase in HC and CO mass emissions with increased load determined in this test program is primarily a result of the increased mass flow of fuel air mixture through the engine. Other uncontrolled gasoline engines have shown a similar effect due to load (1). An increase in load will cause an advance in throttle position and possible change in air fuel ratio; however, the magnitude of the change in load being considered is small and any air fuel ratio effects should be minimal.

An increase in load increases both the concentration and the mass emissions of NO_x . The increased load increases the combustion temperature, on which the formation of NO_x is highly dependent. The data support these statements.

Inertia acts as a load to be overcome during acceleration and deceleration, therefore, the description of the horsepower effects applies to inertia. An increase in throttle setting during acceleration and decrease during deceleration occurs, and with large advances in throttle, the carburetor may deliver a richer air fuel ratio. An examination of the HC and CO concentration data showed no change in concentrations at either end of the inertia range tests, indicating no air fuel ratio caused bias occurred. This supports the relationships obtained by linear curve fitting. The HC and CO data both show a linear increase in mass emissions with increased inertia. The NO_x data also show the expected increase with higher inertia.

(1) The trend is not clear. Data from some gasoline engines have shown no change in HC and CO mass emissions with increases in load.

Fuel economy for both increased inertia and horsepower shows a decrease, as would be expected from the increased mass flow of fuel.

F. Distance Variations

When driving the Federal Urban Dynamometer Driving Cycle, variations in the actual driving distance can be expected due to the driver not being able to exactly follow the driving trace. To determine the magnitude of the variations, dynamometer roll distance was measured on most of the tests. Table V presents the range of distance variations encountered.

Table V
Variations in Dyno Roll Distance

<u>Motorcycle</u>	<u>Standard Distance, km</u>	<u>Range</u>	<u>Mean</u>	<u>σ</u>
Yamaha 125 Enduro	4.665 Bag 1	4.525-4.761	4.651	.066
Yamaha 125 Enduro	6.210 Bag 2	5.998-6.334	6.163	.089
Honda CB360	5.779 Bag 1	5.734-5.838	5.774	.039

Two sigma variations from the standard distance are as large as 3 percent for the Yamaha 125 Enduro.

It is expected that emissions and economy, if calculated using the standard distance, will vary in proportion to the deviation of actual distance from the standard distance. In other words if the UDDS distance was 3 percent long, calculated mass emissions and economy could vary on the order of 3 percent.

The measured effect of distance on emissions was not determined due to an insufficient amount of data. Most of the deviations from the standard distance were small, with only a few values approaching the 3 percent deviation mentioned above. A regression line was calculated but due to the heavy weighting near the mean, it indicated no relationship between distance and emissions existed.

It is recommended that roll distance be measured on future tests and that distance variations and measurement techniques be investigated in the variability study.

APPENDIX

Presented in this Appendix are the statistics of the regression analyses and a description of the application of the regression equations.

At a given inertia and horsepower setting, the test to test repeatability was good, as shown for the Honda CB360 in Table A-1. The test repeatability of the Yamaha was similar.

Table A-1

Typical Test Repeatability at Constant Inertia and Horsepower Setting
Honda CB360*

Inertia kg	Bag	HC		CO		NO _x		Fuel Economy	
		Mean	σ	Mean	σ	Mean	σ	Mean	σ
260	1	1.77	.10	36.30	.90	.18	.01	21.0	.3
210	1	1.65	.07	36.78	1.03	.15	.01	21.1	.4
210	2	1.57	.01	33.40	.36	.05	.00	23.8	.6
290	2	1.83	.04	35.85	.57	.05	.00	22.4	.2

*Emissions in gms/km
 Fuel economy in km/l

The regression statistics for the inertia test series are presented in Table A-2. The bag showing the highest degree of correlation is presented in the table. In many cases the other bag showed insufficient correlation at the 95 percent level. The largest amount of variation explained by any regression equation is 83% (r^2 for the Yamaha HC is .85) with all other relations showing a lesser degree of correlation. If determining an exact relationship between emissions and inertia was required, these data would have only limited value due to the low confidence in the correlation.

Table A-2

Inertia Regression Statistics

Regression Parameter	HC	CO	NO _x	Economy
HONDA CB360				
r	.71	.64	.86	~.71
r reqd. for 95% confidence	.60	.60	.60	.60
Significant @ 95% ?	yes	yes	yes	yes
Slope, a_1	.0024	.0224	.00016	-.01265
Bag	2	2	1	2

Table A-2 (continued)

YAMAHA 125 ENDURO

F	.92	.56	6	=.92
F reqd. for 95% confidence	.67	.67	.67	.67
Significant @ 95% ?	yes	no	no	yes
Slope, a_1	.0100	.0117	0	=.0163
Rsq	.9	.9	.9	.9

But the objective is to evaluate the inertia increment size, and to do this an exact relationship is not required. The data can provide an estimate of the size of the change in emissions (economy) as a function of inertia. The level of correlation, however, should be kept in mind when using the specific results.

The results of the regression analysis are used as follows. The first derivative of the regression equations gives the change in emissions (economy) per unit change in inertia. For example, the regression equation for the Honda NO_x is

$$\text{NO}_x \left(\frac{\text{gms}}{\text{km}} \right) = .00036 * \text{inertia} + .0758$$

and the slope (first derivative) is

$$\frac{.00036 \text{ gms/km}}{1 \text{ kg}} = a_1$$

The percent change of nominal NO_x emissions for the Honda is

$$\frac{.00036 \text{ gms/km} * 100}{1 \text{ kg} * 1.6 \text{ gms/km}} = .22\% \text{ kg}$$

where 1.6 gms/km is the average NO_x emissions for this motorcycle. This calculation procedure is repeated for the other pollutants and fuel economy, and the results are presented in Table II of the discussion section.

The regression statistics for the horsepower test series are presented in Table A-3.

Table A-3

Homeowner Regression Statistics

<u>Model</u>	<u>Regression Parameter</u>	<u>HL</u>	<u>GC</u>	<u>HQ</u>	<u>Economy</u>
Honda CR360	r	.376	.890	.943	.959
	r reqd. for 95% conf.	.75	.75	.75	.75
	Significant at 95% ?	No	Yes	Yes	Yes
	Slope, a_1	.0308	.7424	.0351	-.6931

The regression statistics show there is sufficient correlation at a 95 percent confidence level for all parameters except HL.

The regression equations are used in the same manner as described for the inertia tests. The results are presented in Table IV of the discussion section.